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Increment-Borer Methods for Determining Fire History in Coniferous Forests

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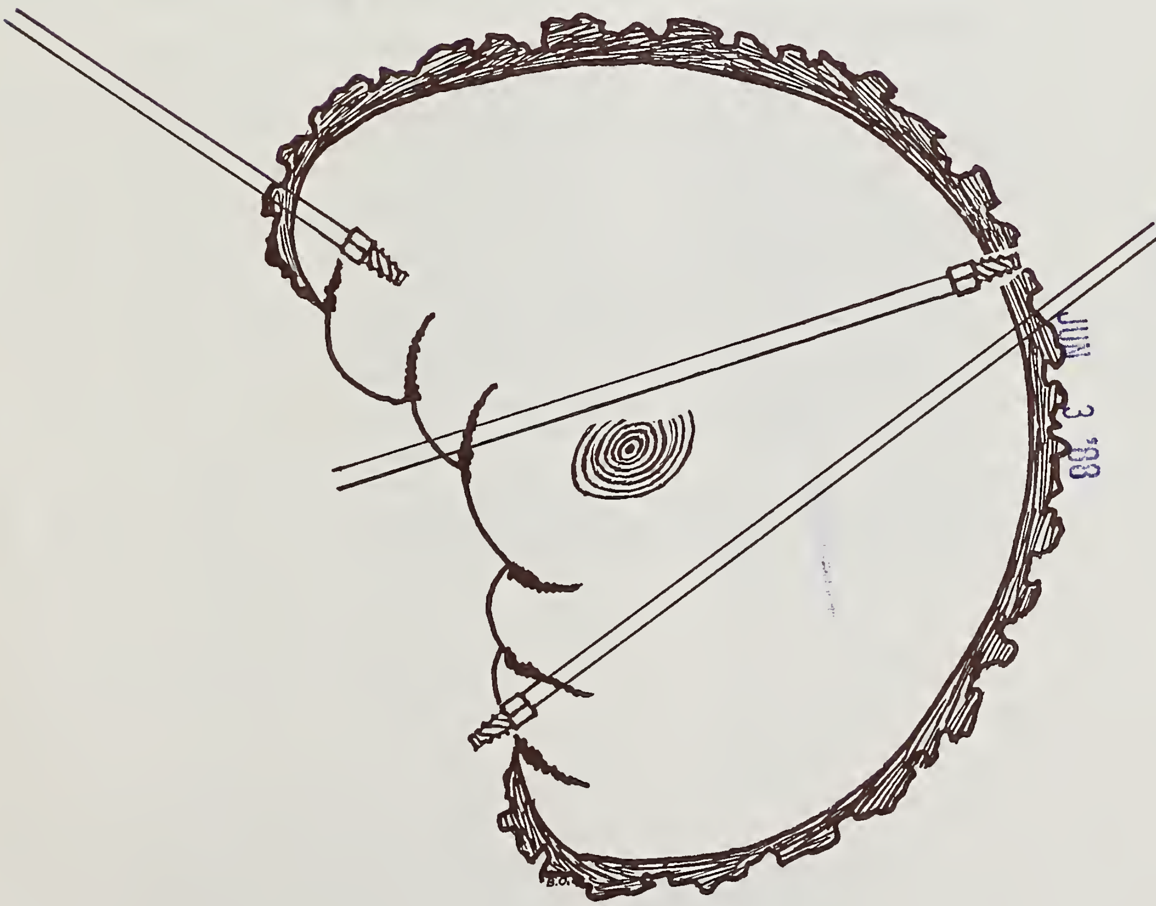

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RESEARCH SUMMARY

This report describes use of increment borers for interpreting fire history in coniferous forests. These methods are especially useful in wildernesses, parks, and other natural areas where fire history is needed for fire management planning, but where sawing cross-sections from fire-scarred trees is undesirable or prohibited.

The techniques presented here can be used to estimate fire years and the length of fire intervals with accuracy sufficient for many needs. Methods described include combinations of scar boring, face boring, and back boring to date individual fire scars; calculations of mean fire intervals for trees with multiple fire scars; and age-class sampling to characterize the effects of past fires on stand structure and composition.

The report discusses selection and layout of study areas and the collection and analysis of samples. The authors tell how to estimate frequency, intensity, and size of fires.

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INTRODUCTION

Information on fire history is important for fire management planning in wildernesses, parks, and other natural areas where management goals include returning fire to a semblance of its primeval role as an initiator of vegetative succession. A few hundred publications and reports describe some aspects of fire history in different localities of Western North America. (For example, see studies listed in Martin [1982], Mastrogiuseppe and others [1983], McBride [1983], and Stokes and Dieterich [1980]). Still, many wildernesses and natural areas lack sufficient fire history information for guiding management. For example, data on frequencies, sizes, burning patterns, and effects of past fires are helpful in developing strategies for using fire to maintain or recreate desired vegetative patterns.

A commonly used technique for obtaining fire history information is by sawing cross-sections from fire-scarred trees (Arno and Sneck 1977; McBride and Laven 1976). But in natural areas such sampling may not be feasible even on a limited basis because of visual concerns, physical damage to trees, or prohibitions on the use of chain saws (motorized equipment). It is also difficult to handsaw "partial cross-sections" from large trees without causing a substantial amount of damage. Occasionally, undecayed stumps can be used to reconstruct fire history (Jacobs and others 1985; Kilgore and Taylor 1979); but most natural areas do not have enough stumps to supply this information.

To overcome these difficulties, we present methods in which increment cores are used to document fire history. These methods are based on a recent exploratory study (Barrett 1987) and on our experience in earlier fire history investigations. Several other investigators (for example, Arno 1976; Frissell 1973; Heinselmann 1973; Means in preparation; Sheppard and Lassoie 1986) have used increment cores to date single fire scars on trees and to identify tree age classes that represent postfire regeneration. No one, however, has produced a comprehensive guide to various methods that can be used for different field situations.

The relatively simple and economical techniques presented here can be used to estimate fire years and the length of fire intervals with accuracy sufficient for many needs in natural resource management and research. (Dendrochronological cross-dating of ring-width patterns on increment cores or tree cross-sections is an optional technique which can increase precision, but at additional expense [Madany and others 1982; McBride 1983; Sheppard and Lassoie 1986; Stokes and Smiley 1968]). The following increment boring procedures can be applied in most coniferous forests in North America. The procedures are intended for situations where sawing of cross-sections is undesirable or prohibited. Otherwise, analysis of cross-sections (Arno and Sneck 1977) is preferable because it is more accurate and economical.

TEST RESULTS OF INCREMENT BORING

In the exploratory study (Barrett 1987), increment cores were obtained from 49 fire-scarred trees. Fire scar years were estimated from the cores and the results were compared with estimates from sawn cross-sections. This sampling was conducted on three areas in western Montana and northern Idaho. Four tree species were sampled successfully with an increment borer: lodgepole pine (*Pinus contorta* var. *latifolia*), ponderosa pine (*P. ponderosa* var. *ponderosa*), interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and western larch (*Larix occidentalis*). In contrast, excessive bole rot prevented increment-borer dating of fire scars on grand fir (*Abies grandis*) and on most western redcedar (*Thuja plicata*). Severe bole rot and indistinct growth rings and scar formations might also hamper increment-borer sampling of fire scars in other species. Therefore, users of this technique should first determine the feasibility of boring the species that occupy the proposed study area.

The following synopsis of study results suggests the levels of precision that can be attained. (More detail on study results is given in appendix A.) On 90 percent of the sample trees having single and double fire scars, fire years estimated from increment cores were within 3 years of those estimated from sawn cross-sections. Sheppard and Lassoie (1986) and Means (in preparation) used increment borers to date single fire scars on high-elevation lodgepole pine and coastal Douglas-fir (*P. m.* var. *menziesii*); they achieved similar levels of precision without dendrochronological cross-dating and greater precision with cross-dating.

We also sampled 11 ponderosa pine and Douglas-fir trees that each had between three and 16 well-preserved fire scars. The mean fire interval (MFI) for each tree based on increment cores was usually within 10 percent of the MFI derived from cross-sections (appendix A). MFI's were determined by (1) systematically counting the number of fire scars on the tree, (2) estimating the years of the

earliest and most recent fire scars that were bored, and (3) dividing the number of years between the first and last fires by the number of fire intervals.

On sites that experienced frequent surface fires, the single-tree MFI's were often much longer than the "site MFI's" (appendix A) calculated from sawn cross-sections of several trees (Arno and Petersen 1983). As explained later, however, it is often possible to closely approximate the site MFI by boring trees that have the largest number of scars and then using the trees with the shortest MFI's to represent site fire frequency.

In forests that burned primarily in severe stand-replacing fires, there usually are few fire-scarred trees to provide a long-term record of fire history. Consequently, we also present an increment-boring technique for characterizing fire history based solely upon the tree age classes that regenerated after fires.

RECOMMENDED SAMPLING APPROACH

The methods outlined here are an extension of Arno and Sneck's (1977) methods for determining fire history from sawn cross-sections. Therefore, this paper concentrates on giving detailed instructions for increment-boring procedures and only briefly reiterates important points from the previous methodology. When possible, cross-sections should be collected because such samples can enhance dating accuracy. In wildernesses and parks, for example, impact can be minimized by cross-sectioning fire scars on stumps, snags, or trees outside but adjacent to the study area.

Selection of a sampling design is guided by study goals. If the goal is to characterize fire history throughout a large and diverse study area, obtain or prepare a map of stands or vegetation types (cover types). The map should also show major topographic differences, such as northern and southern exposures. The stand map (for example, a 7.5-minute U.S. Geological Survey topographic quadrangle) should be based on interpretation of aerial photographs.

Next, use the map to stratify the study area into stand types to ensure that an adequate number of sample sites is selected within each stratum. Transects along roads and trails and elevational contours may be useful for efficient sampling of the various strata (Arno and Sneck 1977).

It should be possible to map the approximate boundaries of past fires if a dense network of sites is selected for sampling throughout the study area (Arno 1976; Heinselmann 1973; Tande 1979). Additionally, where stand-replacing fires occurred, a stand mosaic of fire-initiated even-aged classes can often be identified on the aerial photographs. In such cases, include preliminary sketches of fire margins on the stand map. Fire margins, reflected by different textures on the photograph, can then be verified or adjusted during the field sampling.

The completed fire history maps have useful implications for fire management planning in natural areas. By combining the map with stand structure data (size- and age-classes by species), it is possible to interpret past patterns of both understory fires and stand-replacement fires relative to differences in topography and vegetation types.

FIRE-SCAR SAMPLING

Selecting Sample Trees

If fire scars are present in the sample stands, increment cores can be used to date the scars as well as any fire-induced regeneration. First, conduct a stand reconnaissance to locate the trees that have the clearest, most complete fire-scar sequences containing the greatest number of scars. These trees should also contain wood adequately sound for sampling. A thorough survey and examination of available fire scars will greatly enhance the efficiency of the time-consuming borer sampling and core analyses.

The investigator must also be careful to differentiate between fire scars and those caused by other agents such as mountain pine beetles (Gara and others 1986), root rot (Arno and Davis 1980), or animal or logging damage (Arno and Sneck 1977). Generally, exposed fire wounds ("catfaces") are triangular, and the wound begins at or below ground line. Catfaces usually have relatively uniform margins, in contrast to scars resulting from bark beetle attacks or root rot, which exhibit highly irregular edges and patterns of continuing dieback (Gara and others 1986). Fire wounds often have char on the adjacent bark or, if more than one fire has occurred, on the catface itself. These wounds tend to occur on the uphill side of trees, where heat concentrates during the burning process. On large trees, fire scars usually are centered in hollows between root buttresses rather than directly above a buttress, as is common with root-rot scars.

When possible, choose the most vigorous trees for sampling (for example, dominants or codominants with healthy crowns), because their growth rings tend to be relatively wide and these trees are less likely to have missing growth rings (Stokes and Smiley 1968). Also, species such as pines and Douglas-fir are desirable for sampling because they tend to have distinct scars and growth rings.

After the sample trees have been selected, mark their locations on a topographic map. Nearby topographic or cultural landmarks such as ridges, streams, and trails are useful in pinpointing the stand and sample tree locations (aerial photographs can also be useful). Next, carefully interpret and record the fire scar evidence associated with each tree—this includes the species, diameter, and location of the tree; approximate dimensions of the fire wound; the number of visible fire scars; extent of decay; and tree vigor (Arno and Sneck 1977).

The fire scar count is very important. Each scar is indicated by a distinct fold of healing tissue, which often can be traced along both sides of the catface. Some of the fire scars may have been overgrown (and thus obscured) by healing tissue either locally or throughout the catface. Those that are locally overgrown or locally burned off by subsequent fires can easily be overlooked and must be detected by several systematic inspections of the entire catface (fig. 1).

Here are some hints for interpreting fire-scarred trees in the field: (1) char on the exposed wood of the most recent scar is evidence that another fire subsequently burned this tree—the second fire either failed to scar the tree or its scar is overgrown; (2) char on the outer bark of an apparently unscarred tree is also clear evidence of a fire, but it

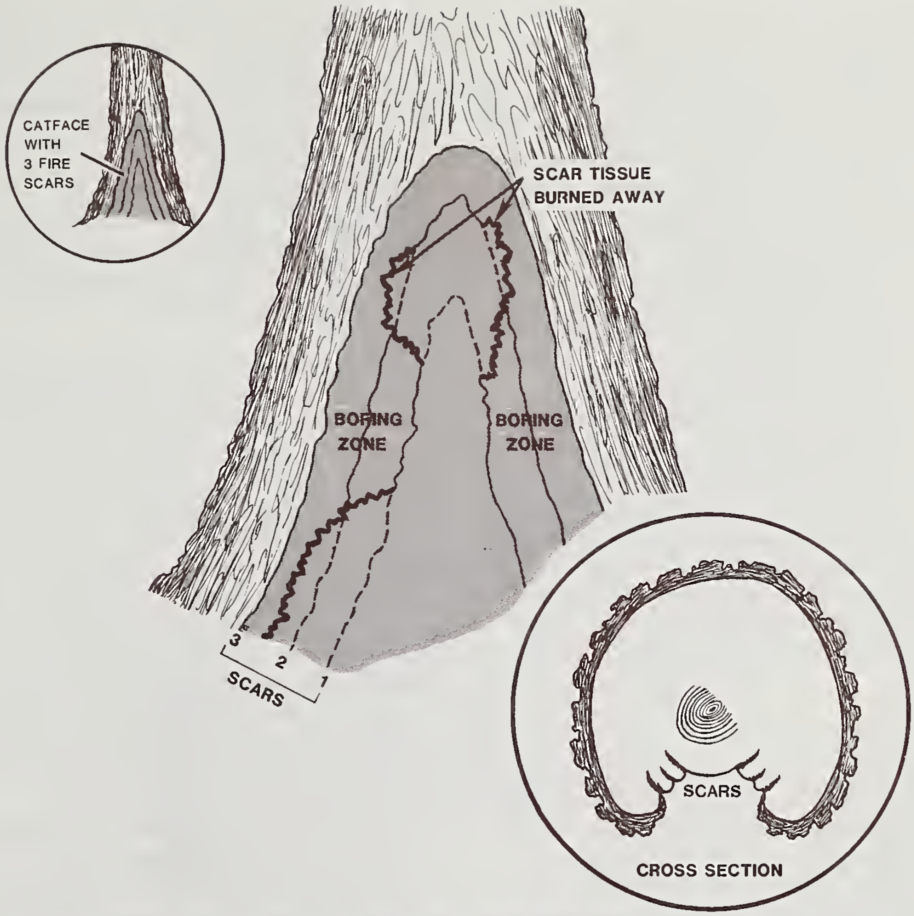


Figure 1—Catface with three fire scars, illustrating the discontinuous remains of some scars and including a cross-sectional view of the scars.

may not have inflicted a scar, so select another tree; (3) finally, a completely overgrown fire scar may be indicated by a prominent vertical bark "seam" on the trunk (fig. 4, page 7).

Preparation for Borer Sampling

A minimum of three increment borers and some spare extractors should be taken into the field because borer-clogging pitch frequently is encountered. If possible, carry borers that can penetrate the full diameter or at least to the center of the largest trees. Short borers are useful for small trees, or for boring scars located near the ground. To obtain clean, datable cores, the borer must be sharp and clean. Maeglin (1979) and Agee and Huff (1986) describe borer maintenance techniques. A dull borer is difficult to drive and will produce a rough core with spiral striations that obscure the growth rings. Periodic sharpening is necessary; the tip is dull when it cannot easily cut through a sheet of paper. A borer that is rusty or pitchy often yields twisted, soiled cores; therefore borers should be cleaned daily. A .22 caliber rifle cleaning kit works well on most borers. Between borings spray the borer and extractor with lubricant to discourage pitch buildup. Lengths of 3/16-inch-diameter hardwood dowels are useful for unjamming borers (0.20-inch core diameter) in the field. (A checklist of field equipment is provided in appendix B.)

Before undertaking fire-scar sampling with an increment borer, it is helpful to become familiar with the patterns of fire scars and tree rings visible on sawn cross-sections of the species that will be studied. When inspecting these cross-sections, visualize the appearance of an increment core that intersects the scar area. Stumps in nearby logged areas or cross-sections gathered during other fire history studies are suitable for this purpose.

At the sample tree, the first step is to sketch a hypothetical cross-section at the height above ground where cores will be taken. That is, sketch the tree as if it were a stump viewed from above (fig. 1). Draw the positions of external scars and hypothesized internal scar patterns on this sketch (fig. 1, inset). Note the approximate distances between scars on the catface and indicate them on the sketch. Each boring pathway will then be sketched relative to the scar locations. Closeup photography can aid in documenting the external appearance of the scar but should not replace the sketches.

While boring a sample tree, record preliminary analyses of the increment cores. For instance, did the core intersect the fire scar? If not, does the core contain any suggestion of a fire injury, such as a pronounced pitch ring or sudden, marked change in growth rate? Also, make field counts to

estimate the approximate year of the scar evidence on the core. Use a 10x hand lens and, if feasible, use a single-edged razor blade to carefully slice a smooth, flat surface on the core to help distinguish suppressed annual rings. As explained later, these rough estimates of scar years will be compared to estimates from other cores taken from the same tree, and also to estimates from nearby sample trees. This rough chronology of fire scar years will help guide the sampling to ensure that adequate repetitive data are obtained for each fire year. Making preliminary fire-year estimates and written interpretations in the field is critical because this information will determine when an adequate sample has been obtained from each tree.

It is also critical to carefully label and store each increment core because inadequately labeled or badly broken cores are unusable. Cores can be stored in plastic drinking straws and placed in protective boxes or map tubes. The core labeling can be done on masking tape stapled to the end of each straw. Label with pencil or water-resistant ink and always make a final confirmation that the labels agree with the field notes and sketches. Label information includes an identification code for the sample stand, tree, and core (for example, "Stand I, Tree 1, Core A").

Boring Methods

Dating of trees with single or double fire scars involves a combination of "scar boring," "face boring," and "back boring." Combinations of these and other boring techniques are used for multiple-scarred trees. In the exploratory study (Barrett 1987) single-scarred trees took a minimum of 15 minutes to sample, whereas old trees with complex, multiple-scarred catfaces required as much as 90 minutes. Sampling generally becomes more complex with increasing numbers of fire scars per tree, with increasing tree ages and diameters, and when rot or obscure growth rings are encountered.

SINGLE-SCARRED TREES

The Scar-Boring Method—This method uses a combination of "scar boring" and "back boring" and is often the most effective approach for estimating the year of the scar on large trees that have a single fire scar. The scar-boring method is generally the most useful approach if the tree's diameter exceeds the length of the increment borers, thereby preventing the use of other techniques described later, or if the tree's center is rotten (Means in preparation). First, choose the best area on the trunk for sampling—identify the section of the catface that has optimum scar development and the least-decayed wood (fig. 1). Boring low on the bole (1 to 2 feet above the ground) can help avoid locally absent areas of individual growth rings occurring higher up on the bole (Zackrisson 1980), which may be a problem on poor sites (Stokes and Smiley 1968).

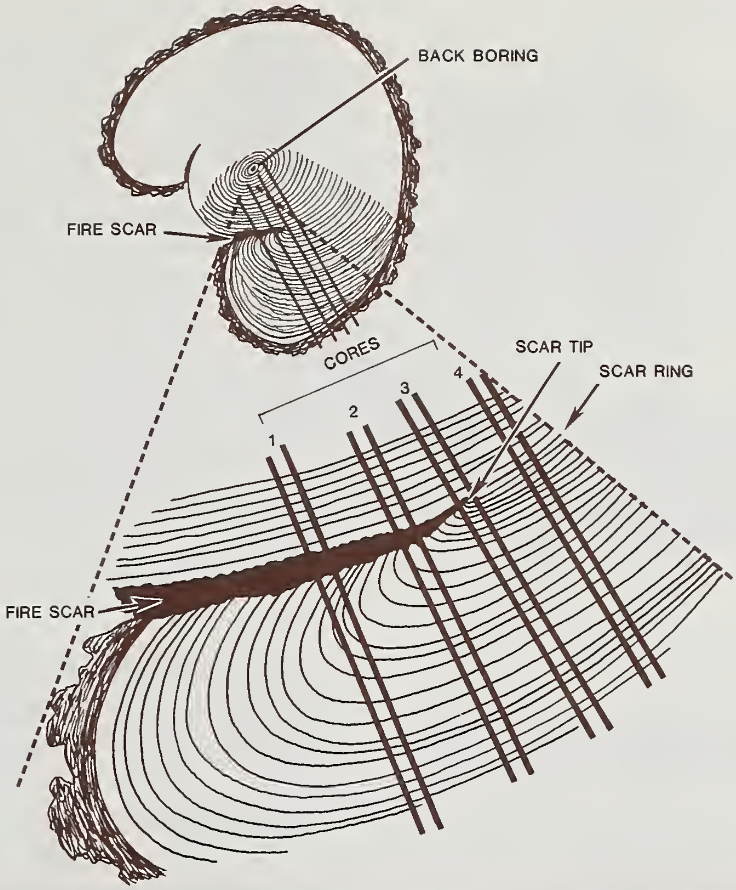
Take the first core from the back (unwounded) side of the tree, from the cambium to the pith (fig. 2). This "back boring" must intersect the pith, or its immediate vicinity, so that pith age can be determined accurately. Make an approximate count of the total age to the pith, and inspect the core to identify any sudden, major change in growth-ring widths that might have been triggered by the fire (fig. 3). If such a growth change occurs near the estimated fire year from scar boring, it can help confirm and refine the fire year estimate. Final scar year determinations will be made in the laboratory, with a microscope, but field estimates will help guide the borer sampling process.

Next, "scar boring" is carried out at the same height on the trunk as the back boring. For clarity, we will describe the process of sampling the right side of a single-scarred catface (fig. 2A). Take the first core so that it intersects the buried "scar ring"—the cambium at the time the tree was scarred (fig. 2, core 1)—2 to 4 inches to the right of the catface.

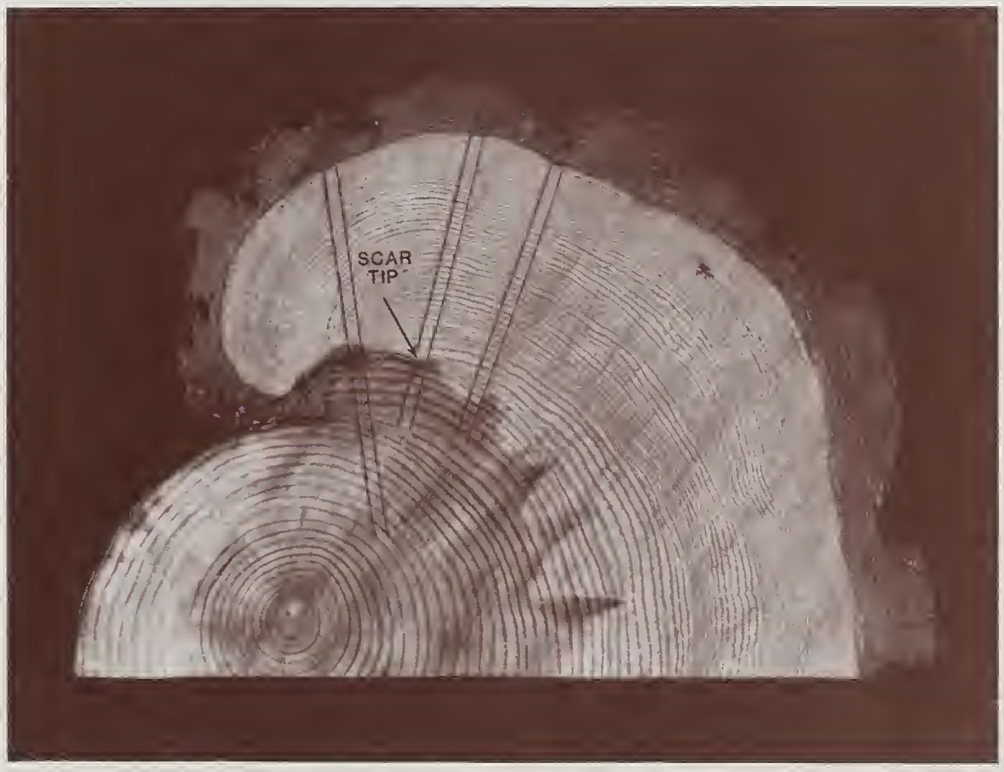
Extract the core and examine it for evidence of the scar ring. The scar ring usually is indicated by (1) a pitch deposit, (2) a change in ring-width pattern, and (3) an abrupt change in color as the first postscar rings covered the scar surface. Also, (4) the scar ring often is disjunct from the subsequent, healing rings because of an anatomical separation of the wood; thus, the increment core readily breaks at the scar ring. Growth rings immediately following the scar ring often (5) slant at an angle, rather than lie parallel, to the other rings in the core. If none of these diagnostic features is present, the borer apparently has missed the scar (in this example, the borer is too far to the right). If this is the case, another attempt should be made to intersect the scar ring by boring closer to the edge of the catface (that is, to the left). After each boring, examine, label, record, sketch, and store the core.

After the scar ring has been intersected, the next step is to make successive borings (to the right in this example), with the goal of intersecting the "scar tip" (fig. 2, core 3). In each of these successive borings, start the borer a short distance farther away from the edge of the catface and bore parallel to the previous attempts. The distance between successive borings depends upon the apparent pattern of scar healing. If the postscar growth rings are wide or if the catface is largely overgrown, make successive borings a few inches apart. Conversely, on slow-growing trees, make the borings closer together (for example, one-half inch apart). In such cases you may have to vary the boring heights slightly to avoid intersecting previous borings.

To improve accuracy in estimating the fire year, it is important to obtain a core that intersects or comes very close to the scar tip. Examine each core for evidence of the scar tip. Using the figure 2 example, if the borer pathway were still to the left of the scar tip, the scar ring would still be discernible, as described above. When the scar tip is approached, however, the scar ring usually becomes less pronounced. Although seldom intersected precisely, the scar tip itself is suggested by a faint line of pitch accompanied by a very slight crack in the core. To verify that the scar tip or the first postscar ring has been identified, take another core slightly past the scar tip (fig. 2, core 4). In this core, postfire growth rings lie parallel to the prefire rings, and there is no intervening pitch deposit or anatomical break. At this time, make a preliminary estimate of the scar year and compare it to estimates derived from the back-boring core and to estimates from other sample trees in the stand. If the full sequence of core samples described here has not been obtained or if a clear interpretation of



A.



B.

Figure 2—A. Scar-boring procedures illustrated on a hypothetical cross-section of a single-scarred tree. B. Scar boring illustrated on an actual cross-section of ponderosa pine, showing the growth patterns that would appear on cores from the outer fire scar.

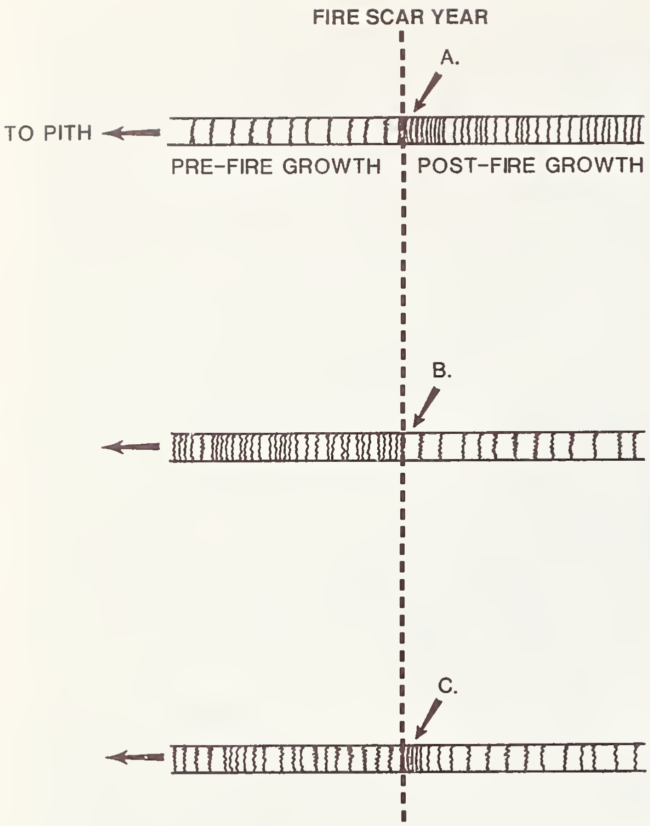


Figure 3—Annual growth-ring patterns commonly associated with fire scarring. These are simulated increment cores taken from beyond the fire scar. A. Fire damage causes marked reduction in growth, including perhaps missing rings; tree recovers slowly. B. Fire does not significantly damage tree, but kills some competitors, resulting in increased growth rate. C. Fire damage causes short-term reduction in the tree's growth, but also reduces competition, thus growth rate ultimately increases.

the scar year is not possible, select another area along the catface and repeat this sequence, or sample another tree.

As an aid to identification, the core that intersects the scar tip area often reveals an abrupt change in growth rate at the scar ring. In this case, the same growth change (fig. 3) should be visible on cores taken beyond the scar tip, and the fire year estimate can be verified from these cores. The core obtained by back boring also should be examined for such a growth change. If the tree was badly scorched by the fire, its immediate postfire growth rings are likely to be extremely narrow, locally absent, or missing entirely, especially near the edge of the fire wound. This appears as a sudden, drastic narrowing of radial growth, followed by a recovery or an increase in growth rate.

Occasionally, additional postfire rings are found in cores taken from the back of the tree or at locations past the scar tip; these represent growth rings that were locally absent near the fire scar. In the laboratory, careful shaving or fine sanding of the increment cores can help determine whether these are authentic annual rings or false rings. Under magnification, the dense summerwood portion of a false ring generally exhibits a gradual transition in both directions to lighter springwood (Stokes and Smiley 1968). In a genuine annual ring, the summerwood ceases abruptly on its outside edge and is followed by the next year's springwood.

The scar-dating procedure in the laboratory is as follows: First, mount the cores in a slotted "core board" (Arno and Sneck 1977) and shave or finely sand the cores. The cores should then be examined in the same sequence in which they were removed from the tree (fig. 2) as a cross-check of the field interpretations. First, count the annual rings in the core that extends from the cambium to the pith (from back boring) and estimate the pith year. Also note any dramatic changes in growth rate near the preliminary estimate of the scar year. Next, date back to the scar ring on the cores obtained from scar boring (cores 1 through 4 in fig. 2). The following list provides an example of evidence recorded from a sequence of cores similar to those in figure 2:

Back-boring core	—1800	estimated pith year at 4-foot sampling height; ~1911 marked growth suppression
Scar-boring core 1	—1915	pitchy scar break
Scar-boring core 2	—1912	pitchy scar break
Scar-boring core 3	—1910	faint pitch line and crack (apparent scar tip)
Scar-boring core 4	—1910	marked growth suppression but no pitch line or crack

The estimated fire year in this example would thus be 1910.

Scar boring also can be used on "seam scar" trees (Means in preparation). On such trees, a vertical bark seam—not to be confused with typical fissures in the bark—indicates that there is a completely overgrown fire scar within the tree (fig. 4). Seam-scarred trees may contain one or, occasionally, multiple buried scars; however, it is extremely difficult to sample multiple seam scars with an increment borer because the number of scars and hence the borer sampling approach cannot be determined visually. To obtain the date of a single seam scar, make a series of scar borings at increasing distances from the seam, until the scar tip is encountered (fig. 4).

The Face-Boring Method—"Face boring" can be used on a single-scarred tree that has relatively sound wood and whose diameter is less than the length of available increment borers (fig. 5). When sampling small-diameter trees, such as lodgepole pine, a single face boring, made in a few minutes, can produce an accurate estimate of the scar year. Face boring can also be used to check the results of scar boring, or it can serve as an alternative method when scar boring has proven unsuccessful because of localized rot or obscure growth rings near the scar tip.

First, examine the surface of the single-scar catface and select a location where the wood is sound and feasible to bore. If the catface is badly weathered or hardened by dried pitch, it is often possible to start the borer in the healing growth barely overlapping the edge of the catface (fig. 5).

Figure 4—An external view and a cross-section of a seam scar.

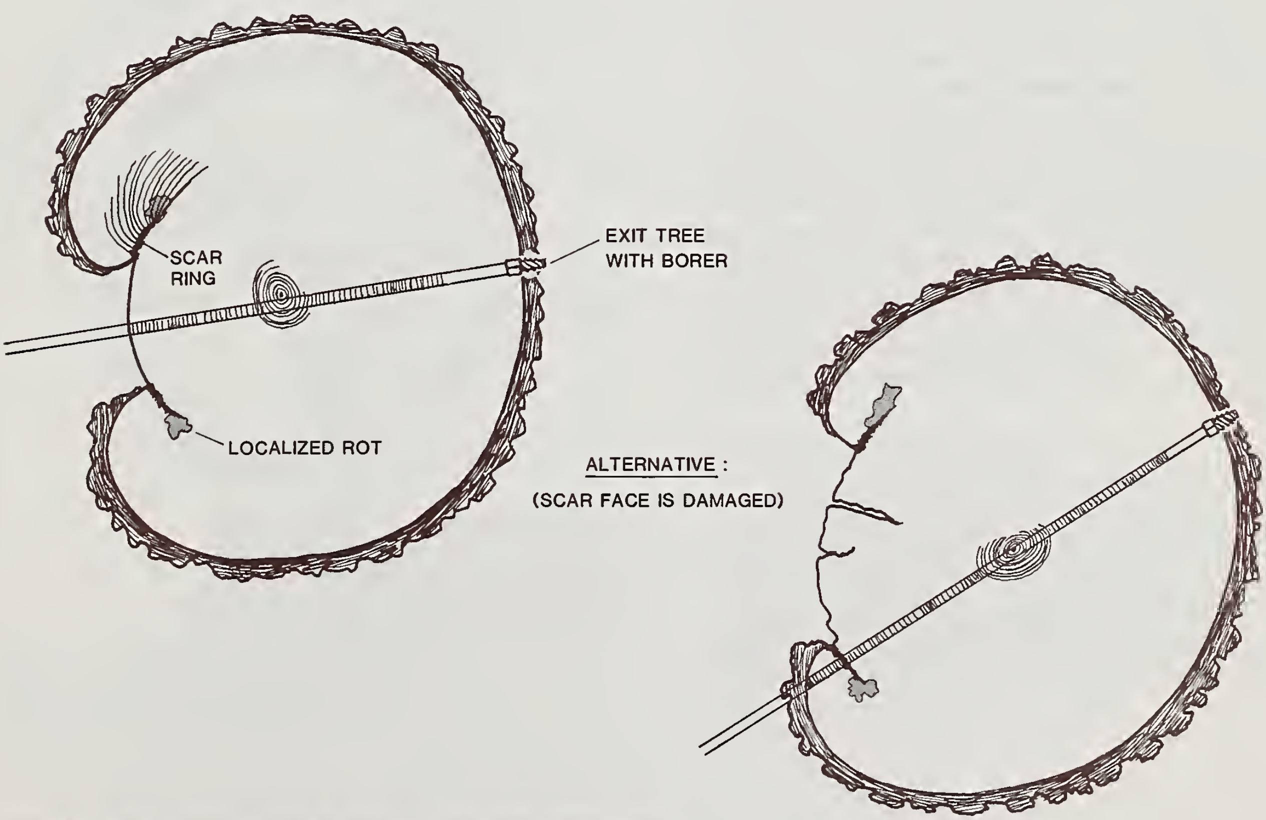


Figure 5—Face-boring procedures illustrated on a single-scarred tree.

Next, bore entirely through the bole. Obtaining the pith is not necessary for determining the scar year, although the pith date can sometimes be useful for estimating the date of tree age-class establishment, as explained later. Be careful to stop the borer as soon as the tip breaks through the bark on the opposite side. (This may be accompanied by a splintering sound.) If all of the screw threads were allowed to exit the trunk, it might be difficult to remove the borer.

It also might be possible to face-bore in reverse ("reverse face boring") by starting the borer on the back of the tree. This can be a useful method if the catface is hardened, damaged, or too deeply enclosed within the tree to bore. The approach is to bore through the tree's center and emerge on the exposed scar or in the adjacent healing tissue. Again, it is not necessary to obtain the pith.

Extract the core and inspect it to see if it contains the scar ring. If the exposed catface was penetrated, the scar ring will have a weathered surface. It may have fallen away when the borer broke through the surface. (This can be prevented by having an assistant hold a block of wood against the spot where the borer is beginning to emerge.) If the scar ring is not found on the core, search for it on the ground, below the borer tip, or bore again—this evidence is essential for estimating the fire year. If the borer emerged in the healing tissue, the scar will usually be indicated by a pitchy ring (previously described) beneath the healing growth.

A continuous core from the catface through the bole to the cambium on the back of the tree (or vice versa) allows for relatively accurate dating of the fire scar. Count the number of annual rings between the cambium and the earliest ring on the core. Subtract this number (of rings) from the date of the cambium to determine the year of the earliest ring. To estimate the scar year, count "up" from the earliest ring to date the scar ring.

If the increment borers are too short to extend through to the opposite side of the tree, a less efficient alternative is to make the face boring to intersect the pith and then a back boring from the cambium to the pith. The back boring should be made slightly below or above the face boring to avoid intersecting its pathway. Because the scar year estimate must be based on two separate cores, the pith must be obtained in both cores. On a large tree if the pith is missed slightly, the number of rings to the pith could be estimated as described by Applequist (1958) and Arno and Sneck (1977).

TREES WITH TWO OR THREE SCARS

The following methods can be used for trees with catfaces containing two or three fire scars. First, if the catface is not badly charred, date the innermost scar using one of the face-boring techniques. Then date the outermost (most recent) scar using the scar-boring approach (fig. 6A). Be careful not to bypass the tip of the outer fire scar and inadvertently sample earlier scars. If the sample tree has three large fire scars it might also be possible to date the middle scar, using either the scar-boring or reverse-face-boring methods. Examine figures 1 through 6 in the field and then experiment with the various techniques to determine which will be most useful.

If the face of the innermost scar has been too badly burned to permit face boring, reverse-face boring should be considered (fig. 6B). In this situation, start the borer on the back side of the trunk and aim through the tree to intersect the healed-over portion of the innermost fire scar. This might require several attempts, but it can be rewarding. Reverse-face boring offers good precision since the scar ring is obtained in a transect through the undamaged center of the tree.

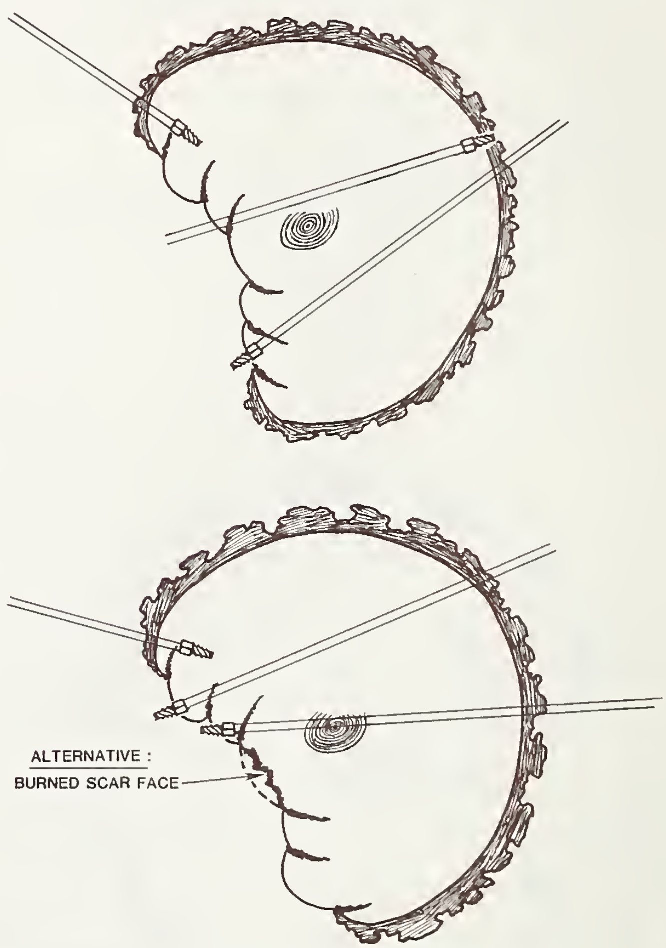


Figure 6—Cross-sections of trees with three well-formed fire scars showing scar boring of the outer scars, face boring of the inner scar in top drawing, and reverse face boring of middle scars and inner scar in bottom drawing.

MULTIPLE-SCARRED TREES—THE MEAN FIRE INTERVAL METHOD

The "mean fire interval" (MFI) method is used when a catface contains three or more fire scars, and it is not possible to date all of the scars. The goal is to date the outermost scar and one of the innermost scars and then estimate the MFI for the intervening period. The MFI equals the number of years between the first fire and the last fire, divided by the number of fire intervals, which is one less than the number of fires.

At the tree, make several counts of the number of fire scars between the outer and inner scars by closely examining the entire periphery of the catface—frequently scars have been locally burned off or overgrown (fig. 1). On old, multiple-scarred trees the earliest fires often cannot be dated because their scars have been destroyed by subsequent fires. In such cases, **the earliest scar suitable for boring** should be chosen as the start of the scar sequence for MFI calculations. As will be explained, however, in a given stand, it is important to sample sequences with the largest numbers of scars.

On trees with relatively few, well-formed scars, the outer and inner fire scars can be sampled with the scar-boring, face-boring, and reverse-face-boring techniques previously described. On old trees with many scars, "exit-scar boring" is often necessary for intersecting the targeted innermost scar (fig. 7). This technique affords less accurate dating than the other methods, but is sometimes the only alternative for determining MFI's, when sawing cross-sections is not possible. Exit-scar boring is similar to scar boring except that the borer is started on the back of the tree and aimed so that the tip exits at the targeted early fire scar deep within the catface. The location of the emergent borer tip and the borer angle allows the investigator to determine which scar was intersected.

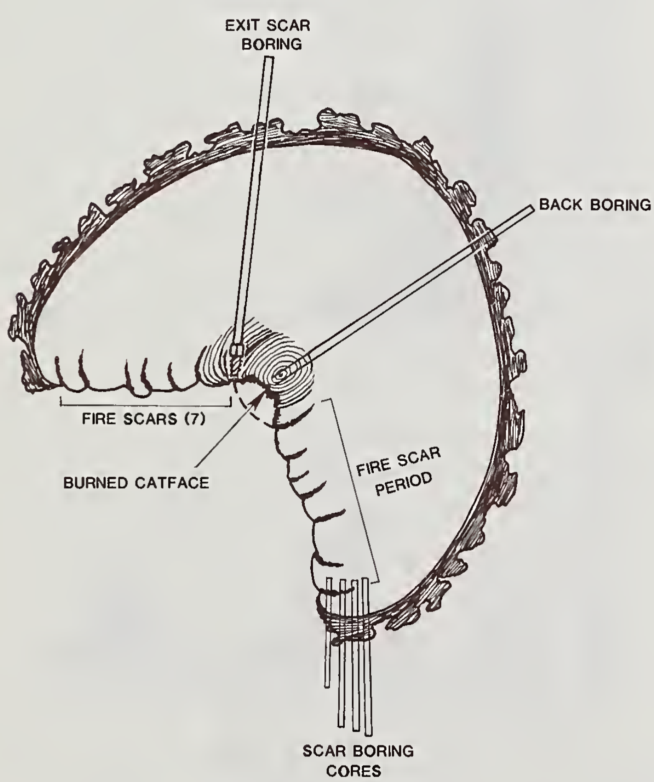


Figure 7—Cross-section of a multiple-scar tree showing possible pathways for exit-scar boring to date inner scars, and scar boring to date the outermost fire scar.

It may take a few attempts to obtain clear evidence of the early scar ring. Even on the best cores, the ring count from the cambium to the early scar probably will represent only the approximate number of years since the early fire. This is because the scar tip is rarely obtained, and locally missing rings are common in old trees that have been scorched by many fires. For characterizing fire history, however, such imprecision often is not a serious problem, because MFI's calculated from the most-scarred trees in the stand usually will be close to those calculated from sawn cross-sections (appendix A).

Along a similar vein, it is important to note that this increment-boring approach produces an estimate of the MFI from an individual tree, or "for a point on the ground" (Arno and Petersen 1983). This contrasts with a "site MFI," which is usually shorter because it is based on a correlation of fire scar records from several trees (Arno and Sneck 1977). If a thorough stand inspection reveals that the most complete scar sequence on any tree contains only a few scars, then the MFI for that tree may well represent the site MFI. But, if the site has been subjected to frequent surface fires, individual trees are unlikely to have been scarred by every fire that occurred during their lifetimes. Thus, even the most complete single-tree MFI will usually be somewhat longer than a site MFI (Arno 1976; Arno and Petersen 1983). To minimize this tendency, sample only the most frequently scarred trees, then use the shortest MFI to represent the best approximation of site MFI. (For example, note that in appendix A several trees were sampled in a grove whose composite MFI was 9 years, yet the individual-tree MFI's ranged from 11 to 21 years). Another limitation is that, unlike the fire record from a sawn cross-section, increment borer sampling cannot provide estimates of minimum and maximum fire intervals or of the distribution of interval lengths.

Age-Class Sampling

In addition to fire scars, many stands have even-aged classes of seral species that became established soon after fires. Age-class sampling is an important component of fire history studies because it helps describe the influence of past fires on forest composition and stand structure. On sites that experienced severe fires, where there are few usable fire scars, age-class sampling may be the primary method for characterizing fire history.

STANDS WITH FIRE SCARS

In forests where past fires can be dated from scars, age-class sampling should still be conducted at each sample site. For example, one goal might be to identify the approximate number of trees per acre by species, sizes, and ages that survived fires, as well as those that regenerated in the postburn environments. These age- and size-class data by species should be collected at each fire scar sample stand, as determined in the stand sampling design. The purpose is to characterize the stand structure relative to the fire history.

First, inspect the stand in the vicinity of the fire scar sample trees to visually identify all apparent age classes of seral trees. Similar tree diameters and crown conditions often are indicative of an age class. For example, one class might consist of immature trees with pointed tops and vigorous leaders; others might have mature trees with rounded tops, overmature trees with flat tops and gnarled upper branches, and senescent trees with thin foliage and gnarled branches throughout the crown (Daniel and others 1979; Keen 1936).

Next, sample a few trees in each apparent age class. Also, in order to interpret successional trends, sample understory trees. Sample size depends on the stand's structural complexity. One approach is to concentrate sampling in one or more macroplots (0.10 to 0.25 acre each) in each stand. Choose the location of plots to include the various age classes found in the stand. Within the macroplots or other sample units, tally all trees by species and by actual diameters or by diameter classes. Tree ages for the major size classes should then be obtained by increment boring.

In most forests, fire-induced age classes are made up largely of shade-intolerant species. Total ages (to the pith) of a minimum of five trees in each potentially fire-induced age class should be sampled by increment boring at 1 foot above ground line. (It is seldom feasible to bore directly at the ground line.) Large trees can be bored higher on the bole if necessary. A correction factor representing an average time necessary for the species to attain the increment boring height should then be determined. This can be done by cutting saplings at ground level and counting the number of years they required to reach the boring height. To characterize the initial height growth of a postfire age class, it may be preferable to gather this information from saplings on disturbed sites rather than in the understory of a dense stand. This factor is added to the ring count obtained from the increment core to obtain an estimate of the tree's total age.

On each sample tree, obtain the pith or its immediate vicinity. A rapid growth rate near the pith is characteristic of regeneration on an open site, and thus of postfire regeneration. Alternatively, if most trees exhibit slow initial growth they may not be fire-initiated.

The oldest trees in a fire-initiated age class provide the best indicator of the fire year, but the establishment dates of even these trees can postdate the burn by a substantial number of years. Nevertheless, age classes of very old seral trees often provide the only estimates of fire years that preceded fire scar evidence.

Enter the data on fire-induced age classes on a stand table (fig. 8) to provide a long-term picture of succession. If stands that experienced numerous surface fires were sampled with the MFI method, the dates of most fires will remain unknown. Still, age-class analysis can reveal the general effect of this pattern of fires on tree regeneration and survival. For example, analysis will indicate whether the stand exhibits several age classes of seral, disturbance-dependent trees that apparently became established in response to the frequent fires. The age-class data also will indicate which species were most abundant in association with the various kinds of fires that occurred in the past. Also, because the year of the most recent fire has been estimated, the investigator can compare current patterns of tree succession and fire occurrence to those of the past.

In stands that did not experience frequent surface fires, scar sampling can often reveal approximate fire years within the last two or three centuries. Inspect the data for any apparent relationships between each tentative age class and the fire years that were estimated for the site (fig. 8).

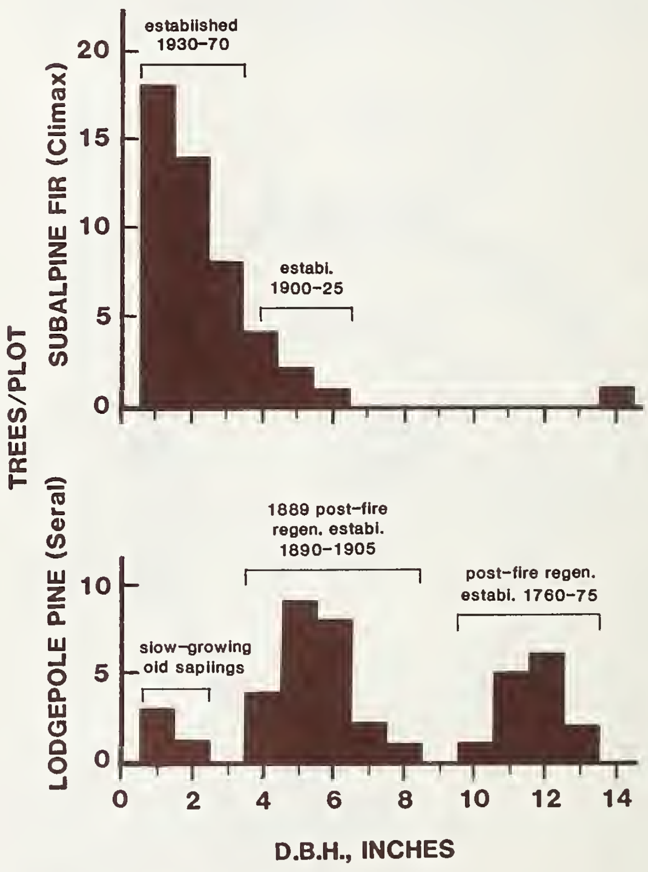


Figure 8—An example of stand table data for a macroplot, showing two fire-induced age classes of lodgepole pine. Trees that are now greater than 10 inches in diameter had survived the 1889 fire and contained fire scars. Most subalpine fir were apparently killed by the 1889 fire.

STANDS LACKING FIRE SCARS

In forests composed primarily of even-aged stands that characteristically burned in severe, stand-replacement fires (for example, Rocky Mountain lodgepole pine), fire-scarred trees may be too scarce or too old and severely decayed to warrant increment-borer scar sampling. In these situations, fire history should be characterized by developing "age-class chronologies."

The first step is to develop a stand-origin map based on interpretation of aerial photographs and examination of fire suppression records (Heinselman 1973; also see our sampling design recommendations on page 2). This map of the forest mosaic shows the pattern of even-aged stands that resulted from the most recent stand-replacing fires. Field sampling must then be done to determine the approximate stand-origin years for the mapped stand mosaic.

An additional goal here is to develop a chronology of initiation years for age classes that occupied the site before the last fire. This evidence of earlier fires is based on the pith years (year of germination) of former age classes of seral species. These often are still represented in the stand as scattered remnant trees or fire-killed snags. First, use aerial photographs and ground reconnaissance to select sample sites that have the largest number of remnant old trees and snags. At each site, in addition to the current age class, datable remnants of at least one prior age class usually can be found (Barrett 1986, 1988).

Begin sampling by estimating the earliest germination year for the current fire-initiated age class. To do this, determine ages (since germination) for a minimum of five seral (shade-intolerant) trees, making preliminary counts in the field. Establishment years of trees in the same fire-initiated age class will often vary by 15 to 25 years or more, but the earliest sampled year provides the best estimate of the fire year. Expanding the number of sample trees might improve the estimate of the fire year. Also, it is often possible to designate the precise year of a 20th century fire by examining fire atlases maintained by land management agencies.

Repeat this sampling procedure to identify any older age classes on the site. The best sample trees are usually found along the margins of the most recent burn. Trees at the burn margins also often have fire scars that can be sampled to improve the estimate of the fire year. Additionally, some trees may have survived on rocky outcrops, stream margins, or other microsites that escaped severe burning. Old snags are often difficult to bore, but it may be permissible to fell and cross-section some snags to date such age classes. Alternatively, it may be possible to locate and saw samples from snags that have fallen in recent years and are not yet badly decayed.

It is important to estimate sample-tree ages in the field in order to identify and adequately sample all age classes on the site. Where snags were created during a known fire year, their age at death can be subtracted from the fire year to obtain the estimated establishment period for this early age class. Table 1 gives an example of fire history data based largely on age-class chronologies. In instances where no datable remnants of a fire-initiated age class can be found in a very old stand, the maximum tree ages evidently represent a long fire interval (Hemstrom and Franklin 1982).

Characterizing Fire Frequency—Age class chronologies provide the sole means of characterizing fire frequency for stands that lack fire-scars. When there is evidence of only the two most recent fires on a site, it is not possible to estimate mean, maximum, and minimum fire intervals. These fire history statistics can, however, be calculated for a network of sites in the same forest zone (for example, the "lower subalpine zone").

First, stratify the sample sites by forest zones. For each zone, list all the individual fire intervals that were identified on the sample sites (table 2). A "multiple-site average fire interval" can then be calculated by totaling the number of years in all the fire intervals and then

Table 1—A hypothetical example of fire history for one site based on age-class chronologies of seral trees. (In this case there are two fire intervals and the MFI is approximately 155 years)

Estimated fire year/ stand-initiation year		Evidence
1910	—	exact year listed in area fire atlas and confirmed by postfire age classes and a few fire scars
approx. 1785	—	based on origin years of seven live seral trees, ranging from ~1785 to ~1805
approx. 1600	—	based on origin years of four seral trees killed in 1910 fire, ranging from ~1600 to ~1620

Table 2—An example of data showing approximate fire intervals among different sample sites within one forest zone. The intervals are compiled (bottom) to derive a "multiple-site average fire interval." Data are from Barrett (1986) for seral species in the "lower subalpine zone" (Pfister and others 1977) of Glacier National Park, MT

Site number	Age-class origin dates			Complete fire intervals (years)
1	~1575	~1780	1929	205, 149
2		~1780		none[1]
3	~1539	~1780	1929	241, 149
4	~1593	~1780		187
5	~1562	~1894		332
6	~1673		1926	253
7		~1720	1910	190
8	~1673		1910	237
9	~1673			none[1]
10		~1750	1919	169
				2,112 yr - 10 intervals

Multiple-site average fire interval = 211 years
Shortest interval = 149 years
Longest interval = 332 years

[1]If numerous incomplete fire intervals are obtained from sample stands, they could be included in calculations of multiple-site average fire intervals, for instance as was described by Arno and Petersen (1983).

dividing by the number of intervals (Means 1982). If there are some very long intervals (complete or incomplete) in the data, it is advisable to consider calculating a median interval rather than the mean described here (Arno and Petersen 1983; Romme 1980). Minimum and maximum intervals can also be identified among these data. If the goal is to characterize fire history for a relatively large area, it is desirable to use well-dispersed sample sites in the calculations, to avoid excessive repetition of some individual fire intervals.

Characterizing Fire Size—Age-class chronologies also can be useful for interpreting size, configuration, and continuity of past fires. (Aerial photographs of the current age-class mosaic will provide an initial impression.) In a large study area (for example, more than 50,000 acres) data from the network of well-dispersed sample sites will suggest which fires were very large. A fire would be interpreted as having been extensive and severe if age-class remnants regenerating from it were found in many different vegetation zones across diverse topography. Conversely, the age-class data from sample sites might suggest that some fires were confined by topographic barriers such as rivers or barren rocklands. Strive for good dispersion and adequate density in the distribution of sample sites, because this will generally enhance your ability to interpret such fire patterns.

CONCLUSIONS

Prior to 1900, fire was a major disturbance agent in most North American forest types. Managers of natural areas are now faced with the challenge of deciding how and when to reintroduce fire. In small areas this might involve manager-ignited prescribed fires. Conversely, in large areas more lightning fires might be allowed to burn under prescribed conditions. In some of the high-fire-frequency vegetation types, it might also be necessary to augment lightning fires with manager-ignited fires in order to prevent undesirable fuel buildups or vegetation changes. Fire history information provides managers with site-specific data on the frequencies, patterns, and general effects of past fires. This information serves as a benchmark for managers to use in maintaining and simulating the forest conditions for which natural areas were established. Use of low impact research methods will help managers determine fire history without damaging wilderness values.

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APPENDIX A: COMPARISON OF FIRE-SCAR YEAR ESTIMATES FROM INCREMENT CORES (BARRETT 1987) WITH THOSE BASED ON SAWN CROSS-SECTIONS (FROM ARNO 1976; ARNO AND PETERSEN 1983; AND UNPUBLISHED DATA)

P = *Pinus ponderosa*; F = *Pseudotsuga menziesii*; LP = *Pinus contorta*; L = *Larix occidentalis*; C = *Thuja plicata*

			Estimated year of first fire		Estimated year of last fire		Mean fire interval (yr)		
Tree No. and species	No. of increment cores	No. of external scars	From cores	Diff. from cross-section	From cores	Diff. from cross-section	From cores	From cross-section	From small stand
				Single-scarred Trees					
1-LP	6	1	1905	+1 yr	NA		NA		
2-LP	8	1	1904	0					
3-LP	7	1	1889	0					
4-LP	5	1	1886	–3					
5-LP	6	1	1891	+2					
6-LP	4	1	1889	0					
7-LP	3	1	1892	+3					
8-LP	5	1	1906	+2					
9-LP	6	1	1911	+7					
10-LP	5	1	1889	0					
12-L	5	1	1903	–1					
13-L	5	1	1806	+1					
14-L	5	1	1904	0					
15-F	5	1	1805	0					
17-F	6	1	1904	0					
18-L	4	1	1905	+1					
8-P	5	1	1922	+3					
10-P	5	1	1920	+1					
11-P	8	1	1919	0					
12-P	5	1	1919	0					
16-F	5	1	1889	0					
17-F	4	1	1889	0					
19-P	4	1	1927	–2					
20-P	7	1	1928	–1					
2-C	6	1	1914	–5					
3-C	3	1	1919	0					
5-C	3	1	1928	+4					
				Multiple-scarred Trees					
9-P	8	2	1877	–6	1919	0	NA		
18-P	8	2	1928	–1	1938	0			
21-P	6	2	1918	–1	1937	–1			
23-P	5	2	1920	+1	1929	0			
2-P	5	3	1643	0	1758	+1	58	57	10
13-F	11	3	1752	–2	1889	0	69	68	19
14-F	6	3	1836	–1	1869	–2	17	17	19
15-F	7	3	1807	+4	1889	0	41	43	19
22-P	4	3	1915	–4	1938	0	12	10	9
1-P	6	4	1815	+5	1889	0	25	26	10
5-P	8	4	1698	+2	1892	0	65	65	9
6-P	11	10	1685	–5	1886	–6	22	22	9
4-P	10	12	1658	–10	1886	–3	21	20	9
7-P	8	14	1659	–9	1916	–3	20	19	9
3-F	6	16	1731	+9	1896	+4	11	11	9

APPENDIX B: LIST OF FIELD EQUIPMENT

–“methods” booklet/photocopied scar illustrations
–tatum (tally board)
–field forms
–7.5 minute topographic maps/aerial photographs
–3 increment borers (16-inch or greater length)
–spare extractors
–plastic drinking straws
–map tubes
–masking tape for labeling cores
–pocket stapler/staples (for stapling straw ends)
–spray lubricant
–wax for borer bit
–$^{3}/_{16}$-inch hardwood dowels
–waterproof pens/pencils
–35-mm camera/film
–10x hand lens
–single-edge razor blade
–pocket knife with multiple tools (awl, screwdriver)

Barrett, Stephen W.; Arno, Stephen F. 1988. Increment-borer methods for determining fire history in coniferous forests. Gen. Tech. Rep. INT-244. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 15 p.

Describes use of increment borers for interpreting fire history in coniferous forests. These methods are intended for use in wildernesses, parks, and other natural areas where sawing cross-sections from fire-scarred trees is prohibited.

KEYWORDS: fire ecology, fire management, forest succession, natural areas, wilderness management

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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